Soft Inelastic X-ray Scattering (SIX) Beamline

IRR Functional Description

Contents

1 INTRODUCTION

Primary Research Capabilities

The SIX beamline, constructed as part of the NSLS-II Experimental Tools (NEXT) project funded by the Department of Energy (DOE), will provide a capability for resonant inelastic soft X-ray scattering (RIXS) experiments with the highest energy resolving power in the world, 10^5 on the beamline and on the spectrometer respectively, for a combined resolving power of 7×10^4. The beamline serves one end station, which is comprised of a sample chamber and an emission spectrometer. The spectrometer will offer the ability to continuously scan the momentum transfer, by swinging around the sample without breaking vacuum.

By exploiting this revolutionary energy resolution and the continuous momentum transfer scan capability, users will be able to probe the collective excitations of the charge, spin and orbital degrees of freedom of correlated electrons in energy materials with unprecedented accuracy. The interplay between these degrees of freedom brings about fascinating phenomena such as topological phases and high-temperature superconductivity, which have the potential to fuel a new era of energy science. The studies carried out at SIX will therefore be directly relevant to the quest for energy sustainability of the DOE.

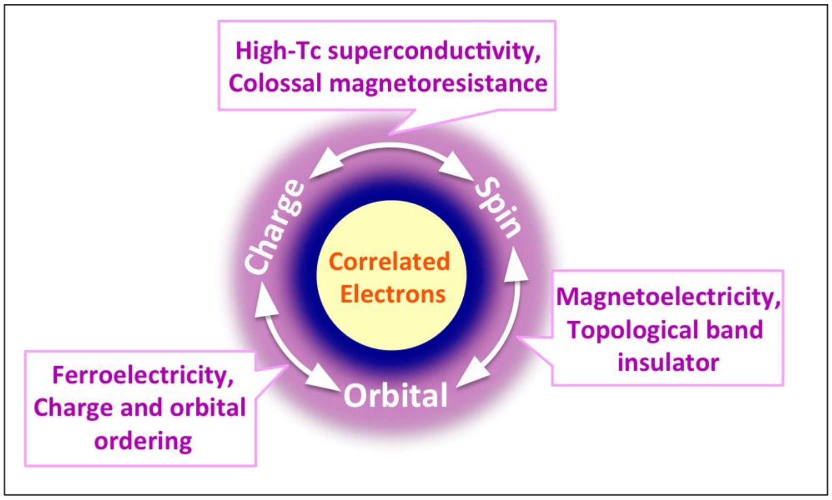

Figure 1. The interplay between charge, spin and orbital degrees of freedom brought about by electron correlation gives rise to a rich variety of exotic phenomena that could fuel a new era of energy science. SIX will be dedicated to studying these phenomena.

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2 BEAMLINE DESIGN AND COMPONENTS

2.1 Beamline Performance Goals

Table 1 summarizes the design performance of the SIX beamline. A set of resolving powers was determined based on the needs of the different experiments envisioned. The optical layout of the beamline (described below) and the specifications of the individual optical and mechanical components are then determined in order to achieve these different resolving powers. The flux performance is estimated using ray-tracing simulations that have incorporated the specifications of the source and the optical components. The actual flux will depend on the configuration of the optical components called for by the experiment.

Table 1. Designed Performance of the SIX Beamline

Parameter	Specification/Description
Insertion Device:	EPU57 (3.5 m long), high-β straight section
Operating Energy Range:	160 – 2300 eV
Monochromator:	Plane Grating Monochromator (PGM). 3 Variable Line Spacing (VLS) gratings (500, 1200, 1800 l/mm, Au coated)
Beam size at sample (FWHM):	0.6 μm (V) x 6 μm (H) (ellipsoidal refocusing optics)
Flux at sample at 500 mA storage ring current:	Up to 1 x 10^{13} ph/sec
Detector system	Soft X-ray CCD

2.2 Beamline Layout

The estimated performance above is based on the conceptual layout of the SIX beamline shown in Figure 2. The source for the SIX beamline is an elliptically polarized undulator (EPU) EPU57, 3.5 m long with a magnet period of 57 mm, installed in the 2-ID high-β straight section. The undulator parameters (Table 2) are optimized to provide continuous coverage in the energy range 15 – 1500 eV.

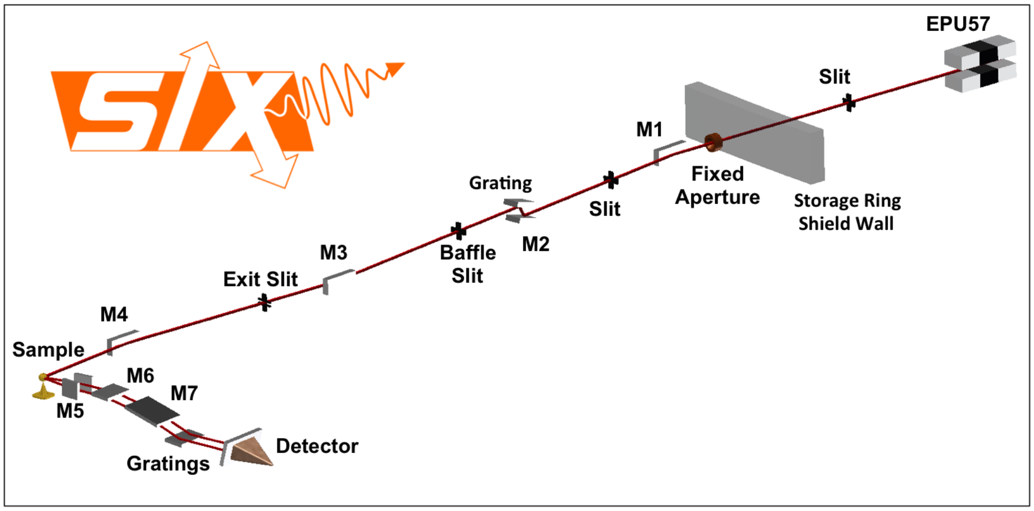

Figure 2. The optical layout of SIX.

Table 2. Main characteristics of the EPU57 for SIX

Device Name	EPU57
Device Type	Ellipt. Pol. Undulator
Period [mm]	57
Length [m]	3.5m
Number of periods	62
Minimum Gap @ High-β Straight [mm]	16
Maximum K	4.42 (160 eV)

In order to achieve different resolving powers that can be required by different types of RIXS experiments over the full energy range, we have adopted a varied line spacing plane grating monochromator (VLS-PGM) design that uses 3 gratings providing 3 resolving powers as detailed in Table 3 below.

Table 3. Main characteristics of the SIX Monochromator

Device Name	Resolving Power	Sample Flux (ph/s)
Medium Resolution Beamline Grating (MBG – 500 l/mm)	14,000	10^{12} - 10^{13}
High Resolution Beamline Grating (HBG – 1200 l/mm)	35,000	$5x10^{11}$ - 10^{12}
Ultrahigh Resolution Beamline Grating (UBG – 1800 l/mm)	100,000	$5x10^{10}$ - 10^{11}

After the monochromator, the beam is intercepted by either the M3 mirror which deflects the beam inboard and focuses the beam horizontally at the PGM exit slit, where a stigmatic focus is generated. Downstream of the exit slit, a single ellipsoidal mirror (M4) refocuses the beam at the sample position.

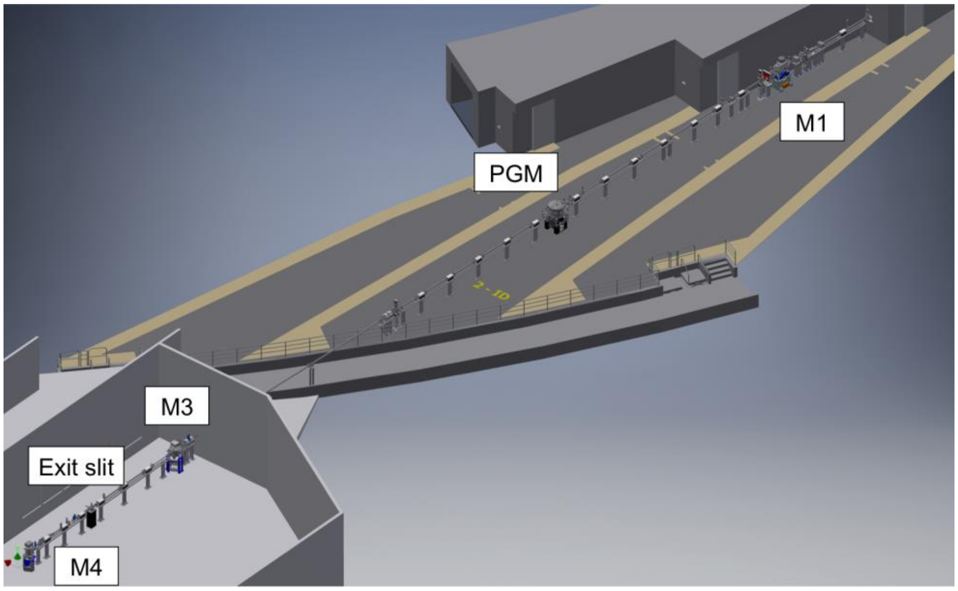

Figure 3. An overview of the components at the SIX beamline

The actual layout of the beamline components is shown in Figure 2. Light emitted by the EPUs enters the first optical enclosure (FOE) at a height of 1400 mm. The only optical element contained in the FOE is the deflecting mirror, M1. This is a directly water cooled plane mirror whose principal function is to reduce the power of the beam sent to the monochromator. M1 also acts as a low pass filter, removing unwanted high energy photons. The M1 mirror deflects the beam outboard by 2.5°. The VLS-PGM is located 20 m downstream of the M1 mirror, on the experimental floor outside of the FOE. It contains a directly water cooled plane mirror (M2) and 3 gratings. The M2 mirror deflects the light upward and the gratings redirect the dispersed light vertically. The height of the beam downstream of the monochromator is therefore offset, 1420 mm above floor height. The next optical element is the exit slit of the PGM, which is located at the focus of the beam (vertically due to the VLS gratings and horizontally due to the M3 mirror) and serves as a secondary source for the final refocusing optics, which is the ellipsoidal mirror M4.

Various types of diagnostic units are available to monitor the quality of the X-ray beam. In the FOE there is the DiagOn optic, which images the soft X-ray radiation from the EPU. It consists of two sets of multilayers deposited on Si wafers and mounted on two water cooled holders made of glidcop, one reflecting the beam horizontally and the other vertically. These multilayers, when introduced along the beam path, reflect the light and produce polarization selective images of the incoming beam.

Each mirror chamber along the beamline is preceded and followed by vertical and horizontal baffle slits to define the shape of the incident beam prior to illuminating the optics and to trim the edges of the reflected beam. The blades of these slits are electrically isolated and can be used as beam position monitors. Furthermore, diagnostics units – consisting of a XUV diode, a Au mesh and a YAG crystal - are mounted at strategic locations along the beamline. Finally, a gas chamber is located after the exit slit for energy resolution characterization.

A 6-way cross is located at the downstream end of the beamline, bolted to the downstream port of the M4 mirror chamber. It will be equipped with a photodiode before the January IRR.

3 BEAMLINE SAFETY

3.1 Radiation Shielding

The design of all radiation shielding (hutches and radiation safety components) will be reviewed to ensure that it follows guidelines to reduce radiation levels external to the beamline enclosures during normal operation to < 0.05 mrem/hr and as low as reasonably achievable. The shielding wall thicknesses follow released shielding guidelines:[1]

Hutch A (FOE, white beam hutch):

- Lateral wall: 18 mm lead
- Downstream wall: 50 mm lead
- Roof: 10 mm lead

A beam shutter of the standard NSLS-II design is installed at the downstream end of the 2-ID-A hutch. An additional NSLS-II standard beam shutter is located downstream of the PGM.

3.2 Radiation Safety Components

These are the components that help contain the synchrotron radiation from the undulator source and the gas Bremsstrahlung radiation from the storage ring. The major components are shown in Figure 3 and described in detail below. The location and dimensions of these components are determined based on the ray-tracing analysis and documented in the ray-tracing drawing. Radiation safety components also include devices such as labyrinths and guillotines. A full list of components are identified in the 2-ID radiation safety components checklist (PS-R-XFD-CHK-011).

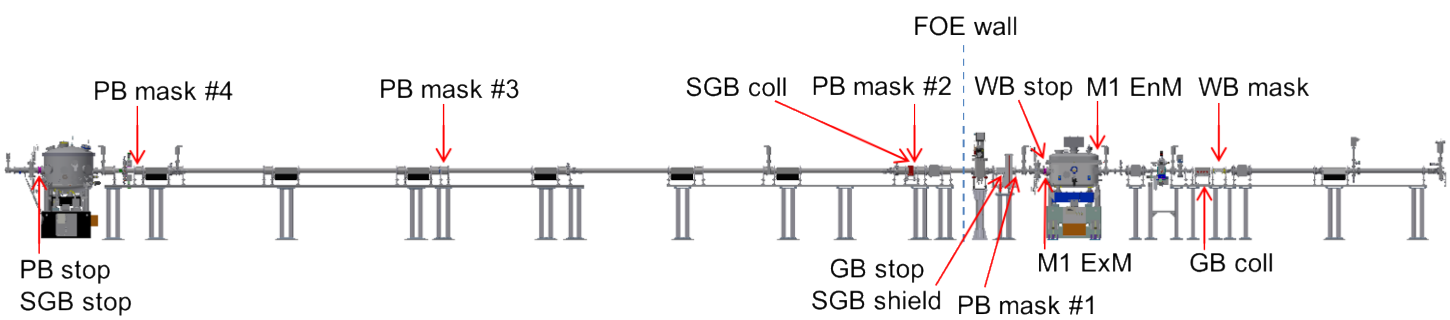

Figure 4. Radiation safety components located in the FOE and the monochromator chamber. Details are given in the text.

3.2.1 Heat Load Management (white and pink beams)

The maximum incident total power from the undulator is expected to be a few kW (EPU57 operated at 16 mm gap). This heat load is limited by the front end water-cooled fixed mask, with aperture size of 0.3 mrad, limiting the maximum power to ~2.7 kW. The white beam mask with aperture size of 0.3 mrad reduces the power down to 1.5 kW. Further reduction of the incident power can be achieved by adjusting the front-end slits. The Au coated, directly water cooled M1 mirror then serves as a low-pass filter and reduces the maximum power of the reflected pink beam to below 200W. The directly water cooled M2 mirror further reduces the pink beam power down to < 10 W incident on the indirectly water cooled gratings.

[1] W.-K Lee et.al., *Guidelines for the NSLS-II Beamline Shielding Design*, (LT-C-ESH-STD-001).

To stop mis-steered white beam from the front end, a set of 3 white beam radiation safety components is provided: a white beam mask (labeled WB mask in Figure 4), the M1 entrance mask (M1 EnM in Figure 4) and white beam stop (labeled WB stop in Figure 4). To stop mis-steered pink beam from M1, a set of pink beam radiation safety componenets is provided: M1 exit mask (M1 ExM in Figure 4), 1 pink beam mask inside the FOE (PB mask #1 in Figure 4), 3 pink beam masks outside the FOE (PB mask #2-4 in Figure 4), and one pink beam stop inside the PGM tank (PB stop in Figure 4).

All the high heat load components are cooled with the same DI water circuit interlocked in the personnel protection system (PPS).

3.2.2 Primary Bremsstrahlung Radiation Management

There are two components for primary Bremsstrahlung shielding: The primary Bremsstrahlung collimator (GB coll in Figure 4) and the primary Bremsstrahlung stop (GB stop in Figure 4). The primary Bremsstrahlung collimator is located immediately downstream of the white beam mask and the primary Bremsstrahlung stop is located just downstream of the M1 tank.

3.2.3 Secondary (Scattered) Bremsstrahlung Radiation Management

Secondary Bremsstrahlung radiation arises from scattering of primary Bremsstrahlung radiation off the white beam mask, the M1 mirror and the white beam stop. Based on NSLS-II guidelines, a secondary gas Bremsstrahlung shield (SGB shield in Figure 4) has been installed downstream of M1 inside the FOE, and one collimator (SBG coll) further downstream outside the FOE. FLUKA simulations[2] have been carried out to verify that the dose rate outside the FOE is below the limit of 0.05 mrem/hr at 500 mA operation current. Furthermore in the PGM tank a secondary Bremsstrahlung stop (SGB stop in Figure 4) has been installed. Additionally, the pink beam vacuum sections outside the FOE and the PGM tank are equipped with a total of 4 pairs of vacuum switches to prevent generation of secondary Bremsstrahlung due to vacuum failure.

3.2.4 Configuration control

All radiation safety components are under configuration control, in accordance with the NSLS-II Radiation Safety Component Configuration Management procedure (PS-C-ASD-PRC-055). Examples are given in Figure 5.

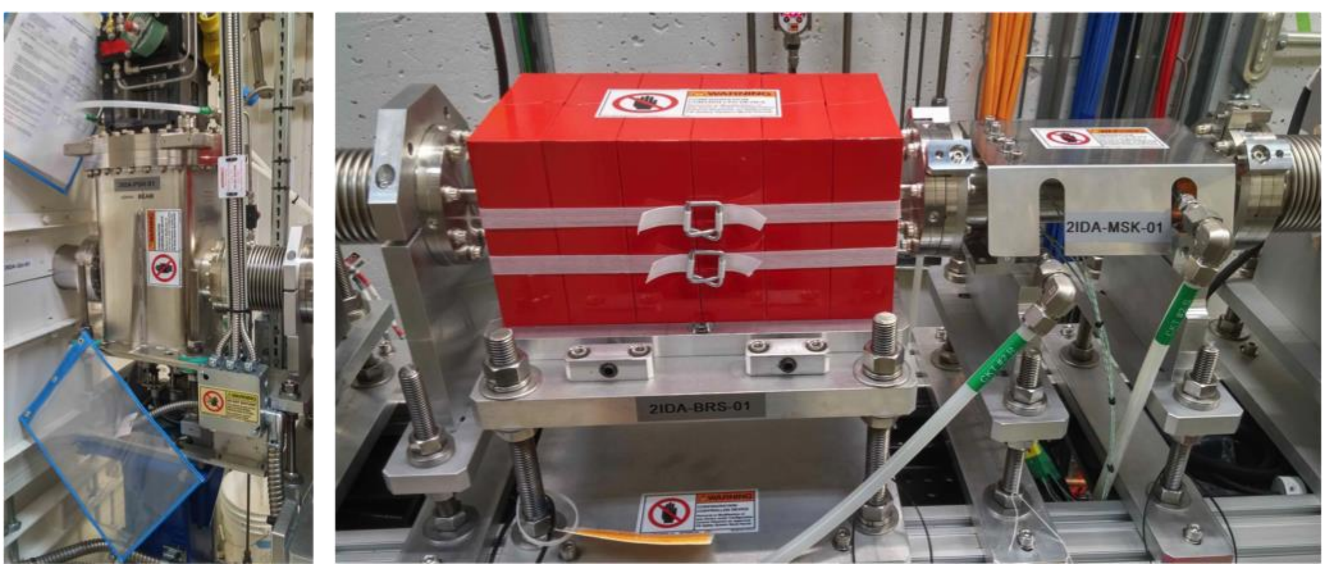

Figure 5. Examples of configuration control on radiation safety components. Left: the photon shutter in the FOE; right: the primary Bremsstrahlung collimator and the white beam stop, both located in the FOE.

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[2] M. Benmerrouche, *2-ID SIX Beamline Radiation Shielding Analysis,* in progress

3.3 Area Radiation Monitor (ARM)

Radiation levels in the area will be actively monitored through an area radiation monitor (ARM) installed on the outboard wall at the downstream end of the FOE. The monitor will be certified in accordance with the procedure PS-C-ASD-PRC-008, *NSLS-II Area Radiation Monitor PPS Test.*

3.5 Personnel Protection System (PPS)

The PPS controls access to the hutches through an interlock system and search and secure procedure, to ensure personnel safety during normal operation of the beamline. The FOE hutch is equipped with a PPS-interlocked user labyrinth to facilitate temporary equipment access during user experiments.

The PPS also monitors critical DI water flow to the beam masks and beam stops to ensure the safe operation of the radiation safety components. In the event that water flow is lost, the PPS system closes the front end photon shutter to shut off the beam.

The PPS also monitors a total of 5 pairs of vacuum switches, 3 pairs in the pink sections outside the FOE, 1 pair in the PGM tank and 1 pair in the M4 mirror chamber.

3.6 Hazard Identification and Mitigation

Overall, the SIX beamline is similar to other beamlines that are already in operation at NSLS-II. A USI evaluation has been conducted and it was determined that the anticipated activities at the beamline do not violate the existing SAD and ASE. All relevant NSLS-II procedures and safety practices were followed during the design and construction of the beamline to mitigate the hazards identified in these document.

4 INSTRUMENT READINESS

4.1 Survey and alignment

The beamline components are installed according to the specifications and the respective final designs. Installations of the components are verified and documented by the NSLS-II Survey group, working closely with the beamline staff.

4.2 Utilities

The following services/capabilities are deployed at the beamline:

- Electrical power distribution: to all electrical power outlets, light fixtures, fans, etc. in the enclosures and along the beamline
- Distribution of deionized water for high heat-load components
- Distribution of process chilled water, water-cooled racks
- Compressed air: for pneumatic valves
- Dry nitrogen gas
- Network connectivity
- Cabling and piping support structures, for all utilities including EPS and PPS.

4.3 Vacuum System and Pressure Safety

The vacuum pressure for all beamline components is expected to be in the 10^{-10}-10^{-9} mbar range. There is no physical barrier between the beamline vacuum and front end vacuum. Instead, two ion pumps are installed upstream and downstream of the white beam mask to provide differential pumping. The effectiveness of these pumps has been confirmed using calculations and will be verified by testing. A fast gate valve sensor is installed just downstream of the front-end-to-FOE interface gate valve (GV2) to protect the storage ring in case of vacuum failure in the beamline vacuum system.

All vacuum vessels are installed with a pressure relief valve to avoid over pressure when the vessel is vented using dry nitrogen. The three pink beam vacuum sections outside the FOE, the PGM and the M4 mirror chamber are equipped with pairs of vacuum switches, which belong to the PPS system.

4.4 Controls

All motorized components have been tested by the Controls Group and documented in the travelers. Controls System Studio (CSS) screens have been prepared to access the motors on the components. The individual motors are also accessible using standard EPICS Extensible Display Manager (EDM) screens.

4.5 Equipment Protection System (EPS)

The EPS at the SIX beamline performs the following functions:

1. Vacuum pressure monitoring and interlock for all the vacuum sections of the beamline.
2. Temperature monitoring and interlock for all non-safety related components, including components exposed to heat load in the white beam mirror system and monochromator.
3. Water flow monitoring and interlock for the cooling of the M1 white beam mirror, M2 and gratings.
4. EPICS interface for components that require I/Os installed on the EPS PLC, including the readout of LVDTs and control of venting and evacuation valves in the experimental station.